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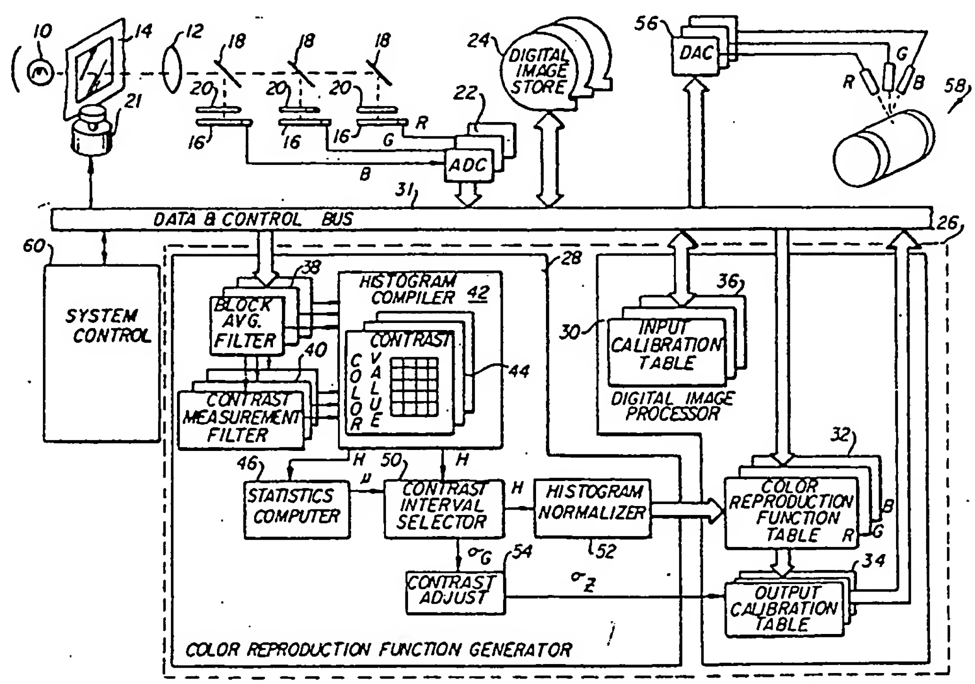

(57) Abstract

A digital color image processing method is characterized by generating color reproduction functions by normalizing samples of color values from the image, and processing the color components of the color digital image by applying the color reproduction functions to the respective color components of the digital color image. The method adjusts both tone-scale and color balance automatically.

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DIGITAL COLOR IMAGE PROCESSING EMPLOYING HISTOGRAM NORMALIZATION

Technical Field

The invention relates to digital color image processing and more particularly, to digital color image processing wherein tone-scale corrections are effected by histogram modification.

Background Art

In the practice of digital color image processing, an original color image, such as a photographic negative, is sampled periodically in three colors (e.g. green, red and blue) to produce a digital representation of the original color image. The digital color image is processed by applying digital image processing functions to improve such image qualities as sharpness, tone-scale, and color balance. The processed digital color image is then displayed on a display medium such as photographic film or paper.

Fig. 2 is a schematic diagram illustrating apparatus for digital image processing. Such apparatus includes an input device 1 for sampling the original color image in each of three colors, and analog-to-digital converters 2 for producing the digital color image in the three colors. Commonly employed input devices include drum and flat bed scanners, linear and area solid state image sensing arrays, and CRT and laser flying spot scanners, each being provided with appropriate color filters to produce the color separations.

Each digital color separation image is stored in a mass storage memory 3, such as a solid state memory frame-buffer, magnetic tape or disc storage device. A digital computer 4 applies the

various image processing functions to the digital color image to produce the processed digital color image.

The digital computer 4 may comprise a main frame general purpose digital computer, or for higher speed operation, a digital computer specially configured for high speed digital processing of color images.

The processed digital color image is converted to sampled analog form by digital-to-analog converters 5 and is displayed on an output device 6 such as a drum or flat bed graphic arts scanner, or a CRT or laser flying spot scanner. The elements of the image reproduction apparatus communicate via a data and control bus 7.

As noted above, among the processing functions performed by the digital computer are the improvement of the tone-scale and color balance of the color image. In the article entitled "Tone Correction of Color Picture by Histogram Modification" by Yoichi Miyake, Nippon Shashin Sakkaishi, V. 48(2), pp. 94-101, 1980, the author proposes a digital color image processing method wherein the tone-scale corrections are effected by modifying the histogram of color values of the green separation image. Color corrections are implemented by solving a conventional set of color masking equations of the form:

$$R' = a_{11}R + a_{12}G = a_{13}B \qquad (1)$$

$$G' = a_{21}R + a_{22}G = a_{23}B \qquad (2)$$

$$B' = a_{31}R + a_{32}G = a_{33}B \qquad (3)$$

where the matrix of color correction coefficients a_{ij} are determined primarily by the characteristics of the input and output media.

In the field of optical photographic printing, it is well known to adjust the coefficients a_{ij} of the masking equations to correct for "problems" in the color balance of the original, such as a color negative film balanced for daylight exposure that was exposed under Tungsten lighting conditions. The correction is usually based upon the hypothesis that the large area integral of the colors in any scene should add up to a shade near gray. Full correction, i.e. forcing the integrated colors in the processed image all the way to gray will correct for problems in the original image caused by such factors as film keeping, incorrect exposure, or an improper match between the illuminant and the film balance. On the other hand, for scenes that do not obey the assumption that all the colors add up to gray (commonly called color subject failure scenes), full correction introduces unwanted color shifts in the printed image. Often some compromise between zero and full correction is employed in optical printers based upon the average characteristics of an expected population of photographic negatives.

This approach results in a large percentage of acceptable prints, but has a shortcoming in that it may not produce an "optimum correction" for any given original. Furthermore, there exists a class of "problem" originals that simply cannot be corrected by adjusting the coefficients of the masking equation. This class includes those originals in which the sensitometric curves cross each other. This phenomena is caused, for example, by severe abuse to the original such as exposure of undeveloped photographic film to formaldehyde.

The objects of the present invention are directed to providing a digital color image processing method for adjusting the tone-scale and color balance of the processed image that overcome the shortcomings noted above.

Disclosure of the Invention

The objects are achieved according to the present invention by adjusting both tone-scale and color balance of a digital color image by modifying the histograms of each of three primary colors in the image.

The method is based upon two principle observations regarding the statistical properties of the color values in a high quality color image. The first of these principles is that a truly random sample of color values (e.g. photographic density or log radiance) in a high quality color image will form a normal (Gaussian) distribution. The second principle is that the standard deviation of a random sample of color values is invarient with wavelength. That is to say, a truly random sample of color values in one color will have the same standard deviation as a truly random sample in another color.

The first principle noted above implies that a function that normalizes a random sample of color values will serve well as a color reproduction function, assuming that any deviation from normality in the random sample was caused by some "problem" with the original. The first principle combined with the second principle noted above implies that color values in all three colors having an equal distance in their number of standard deviations from the mean of their respective color distributions should always combine to produce a shade of gray.

Applying these principles to a digital color image processing method, a color reproduction function for each of three primary colors of the image is generated by normalizing a random sample of color values from each of the three colors. The color components of the digital color image are processed with the color reproduction functions for the respective colors to generate processed digital color image.

In a preferred embodiment of the invention, the sample of color values used to generate the color reproduction functions are taken from an image dependent "floating" contrast interval to optimize the randomness of the sample. The floating contrast interval is selected as a function of the shapes of the histograms of color values for the three primary colors in the contrast interval. This method of choosing a sample of image values is the subject of copending Patent Application Serial No. 730,627. In the preferred embodiment of the invention, the color reproduction functions relate input color values to values of a standard normal variate. The term standard normal variate refers to a scale representing the number of standard deviations of a normal (Gaussian) distribution having a mean of zero and a standard deviation of one. Color components of the digital color image are processed by the color reproduction function to yield dimensionless Z values. The contrast of the processed image is determined by multiplying the Z values by a constant. The color balance of the processed image is determined by adding respective constants representing the mean density of the output medium for the respective colors, to the processed Z values. The basic method

of generating a tone reproduction function and determining contrast in this way is the subject of copending Patent Application Serial No. 730,630.

According to one embodiment, the function of histogram shapes employed to select the contrast interval is the normality of the histogram in one of the three colors, weighted by the similarity of the shapes of the histograms in the other two colors to the one. In another embodiment, the function of histogram shape is the similarity in shapes of all the color histograms in a given contrast interval.

In one embodiment of the invention, the multiplicative constant employed to adjust the tone-scale of the processed image is generated as a function of the standard deviation of the sample of color values in one of the colors (i.e. green).

In an embodiment where the digital image was generated by sampling photographic film having a film grain structure, the image is sampled at full system resolution in three primary colors, then the color values in all three colors are block averaged prior to generating the color reproduction functions to reduce the effects of grain on the sampling process. After the color reproduction function are generated, the full resolution digital color image is processed.

As a further refinement of the method, the total number of color values in each contrast interval is counted, and only the contrast intervals having a number of values greater than some predetermined minimum number are considered for generating the color reproduction functions. This is done to insure a statistically significant sample of color values.

Brief Description of the Drawings

The invention is described with reference to the drawings, wherein:

Fig. 1 is a schematic diagram, illustrating a scanning color photographic printer for carrying out the digital color image processing method according to the present invention;

Fig. 2 is a schematic diagram illustrating generic prior art digital color image processing apparatus useful for practicing the present invention;

Fig. 3 is a schematic diagram showing the organization of the histogram memories;

Fig. 4 is a graph illustrating a color value histogram from one of the contrast intervals shown in Fig. 3;

Figs. 5-8 are flow charts illustrating the method of generating the color reproduction functions according to the present invention; and

Fig. 9 is a graph showing the form of the color reproduction functions generated according to the method outlined in Fig. 8.

Modes of Carrying Out the Inventions

Turning now to Fig. 1, an example of a scanning color photographic printer used to practice the present invention will be described.

The input device includes a light source 10 and lens 12 for projecting an image of color negative film 14 onto three solid state image sensing arrays 16, such as CCD image sensors. The image is directed to the image sensing array 16 by dichroic beam splitters 18 through color trimming filters 20, to form a red, green and blue separation image on the respective image sensors. A film advance motor 21 advances the film in the printer.

The image sensors 16 scan the color photographic negatives to produce three color separation signals R, G and B. The signals thus produced are supplied to analog-to-digital converters 22 that each produce an 8-bit output code representing one of 256 possible signal levels for each sample point in the three colors.

The digital color image signals are stored in a digital image storage memory 24, such as a magnetic tape, disc, or solid state semiconductor memory. The digital color image signals are processed in a digital computer 26, a DEC 2060 mainframe computer was used.

The digital computer 26 is programmed to include a color reproduction function generator 28 and a digital image processor 30 that applies color reproduction functions generated by color reproduction function generator 28 to the digital color image. The color reproduction function generator 28 receives the digital color image from the digital image storage device 24 via data and control lines 31 and generates a color reproduction function table 32 for each color. The color reproduction function generator 28 also generates a multiplicative constant σ_z for adjusting the contrast of the processed image as described below and supplies the constant to three output calibration tables 34.

Prior to storing the digital color image in digital image store 24, each input signal level is converted to an input color value, such as photographic density, by a known scanner calibration function. The calibration function for each color is implemented in the form of a look up table 36 in the digital image processor 30, to convert each

8-bit input value to an 8-bit value representing the color negative density at the scanning point.

The color reproduction function generator 28 includes digital filters 38 for performing a block average of the color values of the color components of the digital color image. Digital filters 40 measure the contrast of the image around each block averaged color value in each of the three colors. A histogram compiler 42 compiles the block averaged color values from a plurality of contrast intervals in each color, in a plurality of histogram memories 44.

Fig. 3 shows, in a graphic way, the organization of each of the histogram memories 44. There are twenty contrast intervals for each color, having a width of .04 log contrast units each. The width of the contrast intervals is chosen to be approximately twice the minimum visual log contrast threshold. The width of the contrast intervals represents a tradeoff between randomness of sampling (the narrower the interval, the greater the randomness) and achieving a sample size that is statistically significant. The 256 color values are divided into 80 color value (density) bins, for a resolution of .05 density units per density bin. Counts are accumulated in the appropriate density bins in the histogram memories until all of the color values from the digital color image are counted. Fig. 4 shows a graphic example of one of the color histograms representing one of the contrast intervals in one of the three colors.

Returning to Fig. 1, a statistics computer 46 in the color reproduction function generator 28 computes the statistical moments μ of the histograms H in the histogram memories 44 as described below.

A contrast interval selector 50 receives the statistical moments μ from the statistics computer 46 and selects a contrast interval on the basis of the statistical moments of the color value distributions in the contrast intervals and supplies the histograms H from the selected contrast interval to a histogram normalizer 52. The histogram normalizer 52 normalizes the histograms from the selected contrast interval to generate the color reproduction function lookup tables 32 that are used by the digital image processor 30.

A contrast-adjustment computer 54 receives the standard deviation σ_G of the green color values in the selected contrast interval and generates a multiplicative constant σ_z used to determine the contrast of the processed image in output device calibration tables 34. All the processed color values in all three colors are multiplied by this same constant.

The color reproduction function lookup tables 32 relate each of the 256 possible input values in the respective colors to one of 256 possible output values. After the color reproduction function lookup tables 32 have been generated, the digital image processor 30 processes the digital image by applying the color reproduction functions to the respective color components of the digital color image. The output calibration functions are then applied to the respective color components of the processed digital color image. The processed digital color image is converted back to analog form by digital-to-analog converters 56. The processed analog signal is then applied to the output scanning device 58 to reproduce the image.

The output device 58 is a drum-type scanner having red, green and blue laser light sources that are modulated by the respective analog color signals to expose a light sensitive medium such as color photographic paper.

System control electronics 60 controls and coordinates the operation of the input and output scanning devices and the digital image processing computer 26.

The method of generating the color reproduction functions will now be described in more detail with reference to the flow charts of Fig. 5-7.

Referring first to the flow chart of Fig. 5, the processing steps performed on the color digital image to generate the respective color reproduction functions will be described. All three color components are processed through these steps. First a block average of the color values of the sampled digital image is formed. This is accomplished by applying a digital filter to the digital image color values of the form:

$$\begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \end{bmatrix} \Big/ 16 \qquad (4)$$

This averaging is performed by the block average filters 38 shown in Fig. 1, to reduce the effects of film grain and other sources of noise on the color value statistics.

Next, a digital filter representing a Laplacian operator of the form:

$$\begin{bmatrix} & -1 & \\ -1 & 4 & -1 \\ & -1 & \end{bmatrix} \qquad (5)$$

is applied to the block averaged color values of the digital image to measure the contrast of the image at each block averaged sample point. This operation is performed by the contrast measurement filters 40 in Fig. 1. The Laplacian operator has the properties of exhibiting no response to uniform areas or linear gradients, and exhibits a response only to changes in gradients. The Laplacian operator works well in measuring the contrast of the modulated color components of the image, however it is to be understood that other contrast measuring filters may be employed with the present invention.

The respective histograms in each contrast interval for each color component are compiled as discussed above, and their statistics computed. A contrast interval is selected on the basis of the shape of the histograms of the respective color values in the interval and the histograms of color values in the selected contrast interval are normalized to generate the respective color reproduction functions.

Fig. 6 is a flow chart showing the steps involved in compiling the histogram statistics. The raw moments μ_k taken about the mean, are computed as follows:

$$\mu_k = \frac{1}{N} \left\{ \sum_{i=1}^{N} (x_i - \bar{x})^k \right\} \qquad (3)$$

where

N is total number of samples in the contrast interval;

x_i is a color value; and

$\bar{x}$ is the mean color value.

The standardized central moments μ'_k are calculated as follows:

$$\mu'_k = \frac{\mu_k}{\sigma^k}, \text{ where } \sigma = \sqrt{\mu_2} \tag{7}$$

The coefficient of symmetry (coefficient of skewness) for each distribution is then represented as

$$\beta_1 = (\mu'_3)^2 \tag{8}$$

and the coefficient of peakedness (kurtosis plus 3) is represented as

$$\beta_2 = \mu'_4 \tag{9}$$

Referring now to Fig. 7A, the steps involved in selecting the contrast interval according to one embodiment of the invention will be described. One selection criteria that has been found to work well is a combination of the normality of the sample of green color values and the sameness of the distribution of the red and blue color values. A function called RANK is defined as follows:

$$\text{RANK} = \sqrt{\beta_{1G}^2 + (\beta_{2G}-3)^2} + |\beta_{1R} - \beta_{1G}| + |\beta_{2R} - \beta_{2G}| + |\beta_{1B} - \beta_{1G}| + |\beta_{2B} - \beta_{2G}| \tag{10}$$

where β_{1G} is the skewness of the distribution of green color values in the contrast interval being evaluated, etc.

The contrast interval with the lowest value of RANK is selected.

In a presently preferred, alternative embodiment of the invention, (shown in Fig. 7B) the contrast interval selection criteria involves the similarity of shape of the three color value distributions in the contrast interval. The selection criteria compares the skewness of the color value distributions in each of the contrast intervals as follows:

$$SUM_1(N) = | \beta_{1_R} - \beta_{1_G} | + | \beta_{1_B} - \beta_{1_G} | + | \beta_{1_R} - \beta_{1_B} | \quad (11)$$

where $SUM_1(N)$ is a measure of the difference in skewness between the three color value distributions in the Nth contrast interval. The contrast interval having the most similar distribution, i.e. the lowest value of $SUM_1(N)$ is identified.

Next, the peakedness of the three color value distributions in each contrast interval is compared as follows:

$$SUM_2(N) = | \beta_{2_R} - \beta_{2_G} | + | \beta_{2_B} - \beta_{2_G} | + | \beta_{1_R} - \beta_{1_B} | \quad (12)$$

where $SUM_2(N)$ is a measure of difference in peakedness between the three color value distribution in the Nth contrast interval. The contrast interval having the most similar distributions, i.e. the lowest value of $SUM_2(N)$ is identified.

Finally, the lowest contrast interval (i.e. the interval representing the lowest contrast) between the two identified contrast intervals is selected.

Optionally, to insure that there is a statistically significant number of color values in the contrast interval, a check on the total count of color values in the interval is performed. If the total count in each color is less than some

predetermined number, say 1000, the contrast interval is not selected. This check is continued until a contrast interval having at least the required minimum number of color values is chosen.

Turning now to Fig. 8, the steps involved in normalizing the color histograms in the selected contrast interval to generate the color reproduction funcations will be described. To normalize a histogram, the standard normal variate Z for all 80 color value bins in the contrast interval is computed. First however, an average smoothing operation is performed on the selected histogram to remove any spikes. The smoothing is performed on the counts in 3 consecutive color value bins as follows:

$$h_i = 1/3\ (h'_{i-1} + h'_i + h'_{i+1}) \quad (13)$$

where h'_i is the count in bin i and h_i is the smoothed value.

Next, the standard normal variate Z is calculated for the smoothed values of the histogram as follows (from Approximations for Digital Computers, Hastings C., Princeton Univ. Press.):

$$Z_j = t_j - \frac{a_0 + a_1 t_j}{1 + b_1 t_j + b_2 t_j^2} \quad (14)$$

where

$$t_j = \sqrt{\ln (1/P_j^2)}$$

$$a_0 = 2.30753 \qquad b_1 = .99229$$

$$a_1 = 0.27061 \qquad b_2 = .04481$$

The probability P_j for each of the 80 bins is given by

$$P_j = \frac{\sum_{i=1}^{j} h_i}{\sum_{i=1}^{80} h_i} \quad (15)$$

where

h_i are the smoothed counts in the ith color value bin, and

$j = 1 - 80$.

Next, the Z values are linearly interpolated from 80 to 256 values to provide a Z value for each of the 256 possible scanner inputs represented by the 8-bit digital code. Finally the 256 Z values are stored in the color reproduction function lookup tables 32. This process is applied to each of the three samples of color values in the selected contrast interval.

Fig. 9 is a graph showing the form of the color reproduction functions produced by normalizing the samples of color values. In the lower right quadrant of the graph, a curve labeled 70 represents a standard normal distribution showing the probability of the occurrence of a value plotted against the standard normal variate Z. In the upper left quadrant of the graph, the curve labeled 72 represents the sample of color values from the image, plotted against relative probability of occurrence. The central ordinate of the graph relates the relative probability P_j of the color value distribution to Z values according to the relationship defined by equation 14. The color reproduction curve, labeled 74, maps the Z values on the ordinate to the same Z values on the abcissa. A color value scale on the far upper right of the diagram, congruent to the color value scale on the far left, shows how the color reproduction function relates color values to Z values.

After the three color reproduction function lookup tables are generated, all of the color values of the image are processed by applying the

respective color reproduction functions to them. At this point, the processed color samples from the image are dimensionless quantities representing the Z values.

To recover the processed image, these dimensionless quantities are given magnitude with respect to the original image and the output medium by multiplying the Z values with a multiplier σ_z that adjusts the contrast of the processed image. To adjust the color balance of the image, a constant term is added to each of the three color values. The constant term relates the Z values in each color to the mean density of the output medium for the respective color, thereby causing equal Z values in all three colors to be reproduced as a shade of gray.

Appropriate values for the multiplier σ_z that adjusts contrast and the additive constants that determined the color balance of the processed image are determined as follows. The multiplier is computed based on the statistics of the green color values alone, but is applied to all three colors. The intrinsic contrast of natural scenes can be quantified in terms of the standard deviation of log reflectance of edges in the scene or the density representation of those log reflectances in the photographic image. On the average the approximate relationship between the two is given by:

$$\sigma_D = \bar{G} \cdot \sigma_R \qquad (16)$$

where:

$\bar{G}$ = average gradient of the photographic film (relates σ_R to some specific reproduction medium contrast)

σ_R = standard deviation of log reflectance based on a large number of original scenes

σ_D = standard deviation of density

Typical values for σ_R and $\bar{G}$ for color photographic film are .31 and .68 respectively, such that σ_D is .21. Departures from this average contrast must be compensated. A general equation may be stated as:-

$$\sigma_z = m \cdot f(\sigma_s) + b \qquad (17)$$

where:

σ_s = individual scene standard deviation, from the selected contrast interval

m and b are system dependent constants and

$f(\sigma_s)$ is some function of the sample standard deviation

σ_z = the multiplier applied to the values obtained from the color reproduction function.

A simple and satisfactory implementation is obtained from:

$$b = \sigma_D \cdot (1.0 - m) \qquad (18)$$

$$\sigma_z = m \cdot \sigma_s + b \qquad (19)$$

where:

m is typically between .6 and .8.

The sign of σ_z is positive if the reproduction has the same polarity as the original image (negative-to-negative or positive-to-positive). If the reproduction has a polarity of an opposite sense with respect to the original, e.g., negative-to-positive, then the sign of σ_z is negative.

Note that the adjustment of the contrast in (19) does not affect scenes having the average contrast (σ_D), nor does it affect the mean value

of tone in the scene, since in terms of Z (the normal variate) the average value remains 0. This is not only a computational convenience in terms of adjusting the contrast, but also in adjusting the color balance of the processed image with respect to the reproduction medium. For example, if a color negative image is to be printed directly onto color photographic paper, the log exposure for the desired mean paper density for each color is simply added to the translated, contrast adjusted values of the respective colors. The complete calculation is given by:

$$\log E_{ZD} = -\sigma_z \cdot Z_D + \log E_A \qquad (20)$$

where:

$\log E_A$ = log exposure required to obtain the aim paper density

Z_D = translated Z value for some input density in the original image

$\log E_{ZD}$ = log exposure for Z_D.

Industrial Applicability and Advantages

The digital color image reproduction method according to the present invention is useful in the graphic arts and photographic printing fields to provide automatic tone-scale adjustment and color balance of digitally processed images. The method is advantageous in that a greater percentage of high quality images are produced automatically, without the need for operator intervention, than by the methods of the prior art.

By processing the color values according to the present invention to yield dimensionless quantities relating to the statistical distribution of color values, the tone-scale and color balance of the processed image are easily adjusted by the simple acts of multiplying the processed values by a

constant to adjust the tone-scale, and adding a constant to the tone values in each color representing the mean density of the output medium to adjust the color balance. Because the processing of the original digital color image does not involve dimensioned quantities until the last step, the processing is completely independent of the output medium until the last step is performed. The method therefore has the advantage that changing from one output medium to another is easily accomplished by simply changing the constants representing that mean density of the output medium desired. Under and over exposure are automatically compensated, since the correction depends on the expectation of normally distributed density, and not on a priori information about film sensitometric characteristics. An additional advantage of the method according to the present invention is that color corrections are automatically performed by the method that would be impossible using the prior art methods.

Claims

1. A digital color image processing method characterized by: generating color reproduction functions by normalizing samples of color values from the image, and processing the color components of the color digital image by applying the color reproduction functions to the respective color components of the digital color image.

2. The digital color image processing method claimed in Claim 1, wherein said samples of color values from the image are selected from an image dependent contrast interval based upon the similarity in shape of the distribution of color values in the contrast interval.

3. The digital color image processing method claimed in Claim 1, wherein said color reproduction functions relate input color values to values of a standard normal variate Z, and wherein the tone-scale of the processed image is determined by multiplying the Z values by a constant, and the calibration is accomplished with respect to a particular output medium by adding a constant to processed color values representing the mean density of the output medium for the respective color.

4. The digital color image processing method claimed in Claim 3, wherein said contrast determining constant is a function of the standard deviation of one of the samples of color values.

5. The digital color image processing method claimed in Claim 4, wherein said function is of the form:

$$\sigma_z = m \cdot \sigma_s + b$$

when

σ_z is the contrast adjusting constant,

σ_g is the standard deviation of the sample of green color values, and

m and b are system dependent constants.

6. A digital color image processing method for adjusting the tone-scale and color balance of the processed image, characterized by:

a) generating a color reproduction function for each of three primary colors by normalizing a random sample of color values from the image in each of the three colors;

b) processing the color values of the image in the three primary colors using the respective color reproduction functions for the colors to generate processed values representing a number of standard deviations from the mean for each color value;

c) multiplying the processed values by a constant to adjust the tone-scale of the processed image; and

d) adding a constant representing the mean density of the output medium for each of the three colors to the respective color values of the three colors to calibrate the output image with respect to a particular output medium.

7. The invention claimed in Claim 6, wherein the samples of color values employed to generate the color reproduction functions are from an image dependent "floating" contrast interval.

8. The invention claimed in Claim 7, wherein the "floating" contrast interval is selected according to predetermined criteria relating to the shapes of the histograms of the color values in the contrast interval.

9. The invention claimed in Claim 8, wherein the predetermined criteria is a function of the normality of the histogram of one of the colors, and the similarity of the shape of the histograms of the other two colors to said one.

10. The invention claimed in Claim 8, wherein the predetermined criteria is a function of the similarity of shape of the histograms of the three color values in the contrast interval.

11. The invention claimed in Claim 6, wherein the constant multiplier employed to determine the tone-scale of the processed image is generated as a function of the standard deviation of the sample of color values of one of the colors.

12. The invention claimed in Claim 7, wherein the contrast interval has at least a minimum number of color values.

13. Apparatus for processing a digital color image to adjust the tone-scale and color balance of the processed image comprising:

a) means for scanning the image in three colors to produce color values and contrast values in each color;

b) means for selecting a random sample of color values from each color;

c) means for generating a color reproduction function for each of the three colors by normalizing the random sample of color values in each color;

d) means for processing the color values of the image in the three primary colors using the respective color reproduction functions for the colors, to generate processed values representing a number of standard deviations from the mean for each color value;

e) means for generating a contrast adjusting constant based on the standard deviation of the sample of one of the colors;

f) means for multiplying the processed values in all three colors by the contrast adjusting constant to adjust the tone-scale of the processed image;

g) means for adding a constant representing the mean density of the output medium for each of the three colors to the respective color values of the three colors to calibrate the processed image with respect to a particular output medium.

14. The invention claimed in Claim 13, wherein the means for selecting a random sample of color values from the image selects said sample from an image-dependent "floating" contrast interval.

15. The invention claimed in Claim 14, wherein said means for selecting a random sample from a "floating" contrast interval selects said contrast interval according to predetermined criteria relating to the shapes of the histograms of the color values in the contrast interval.

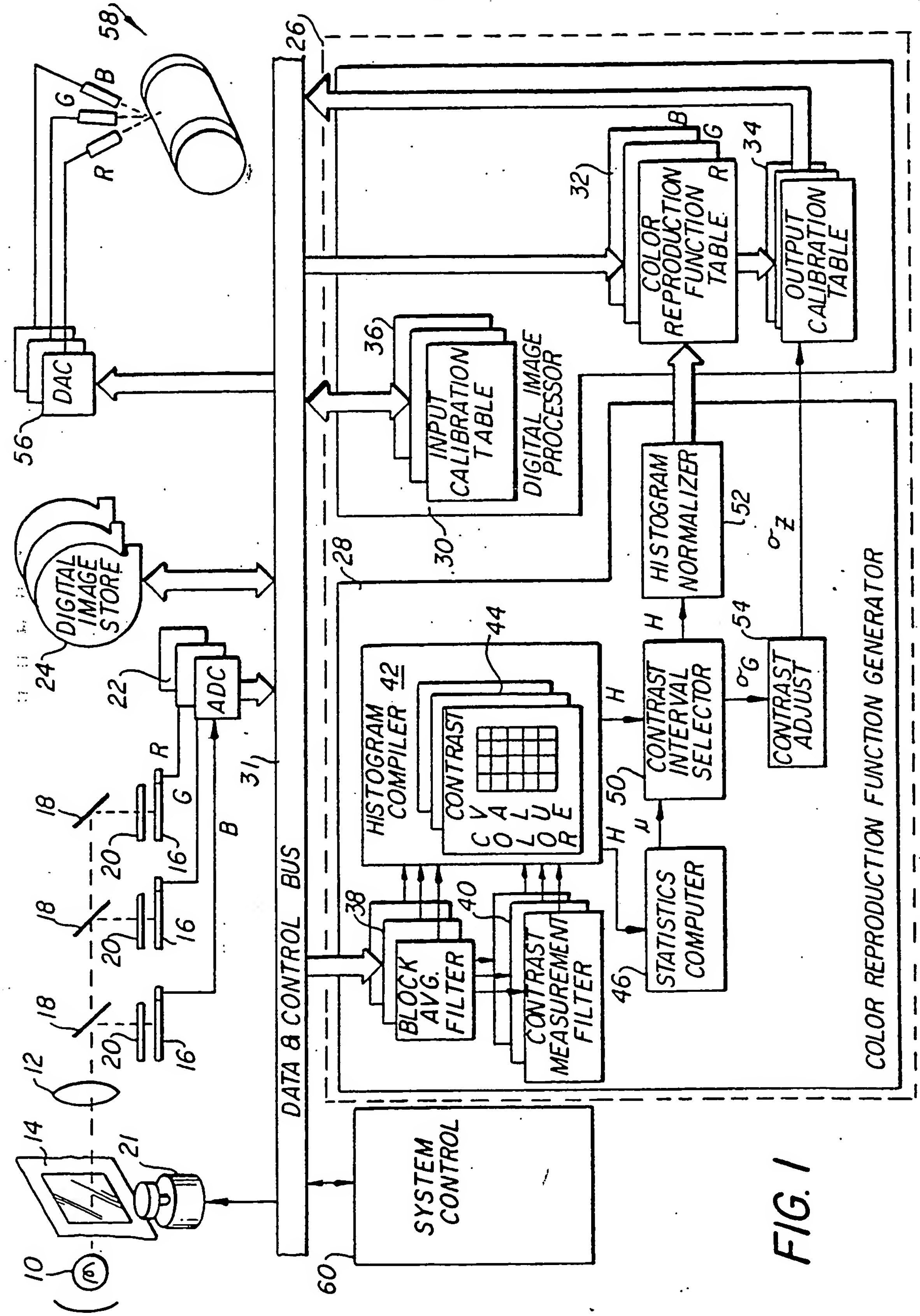
DIGITAL IMAGE STORE
DAC
ADC
INPUT CALIBRATION TABLE
DIGITAL IMAGE PROCESSOR
COLOR REPRODUCTION FUNCTION TABLE
OUTPUT CALIBRATION TABLE
HISTOGRAM NORMALIZER
HISTOGRAM COMPILER 42
CONTRAST VALUE COLOR
CONTRAST INTERVAL SELECTOR
CONTRAST ADJUST
STATISTICS COMPUTER
BLOCK AVG. FILTER
CONTRAST MEASUREMENT FILTER
COLOR REPRODUCTION FUNCTION GENERATOR
DATA & CONTROL BUS
SYSTEM CONTROL
R
G
B
H
μ
σ_G
σ_Z
10
12
14
16
18
20
21
22
24
26
28
30
31
32
34
36
38
40
44
46
50
52
54
56
58
60

FIG. 1

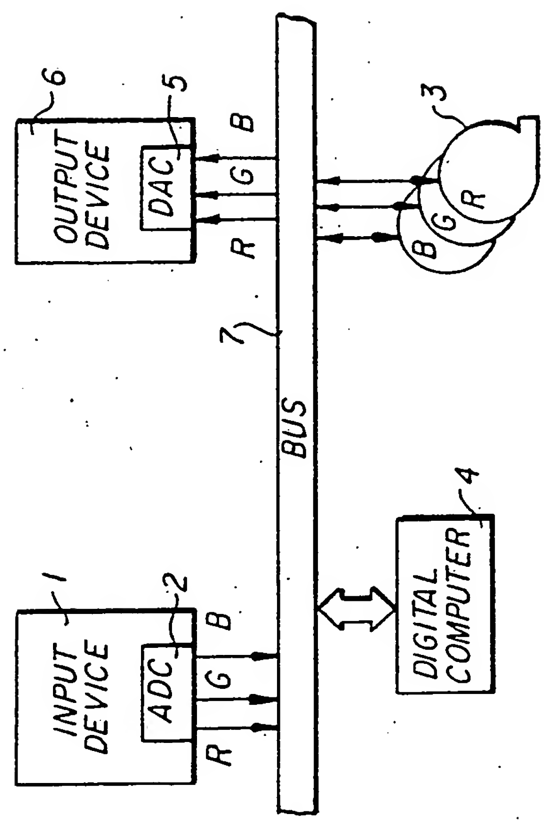

FIG. 2 (PRIOR ART)

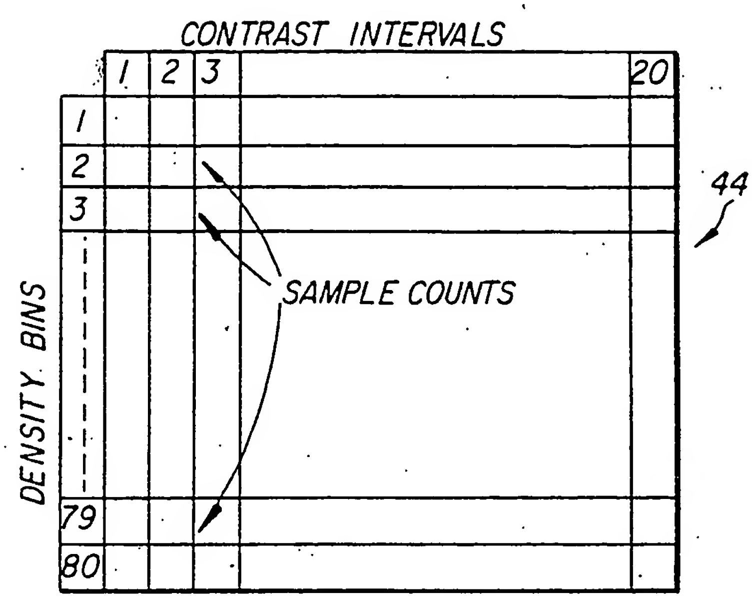
CONTRAST INTERVALS
1
2
3
20
DENSITY BINS
1
2
3
79
80
SAMPLE COUNTS
44

FIG. 3

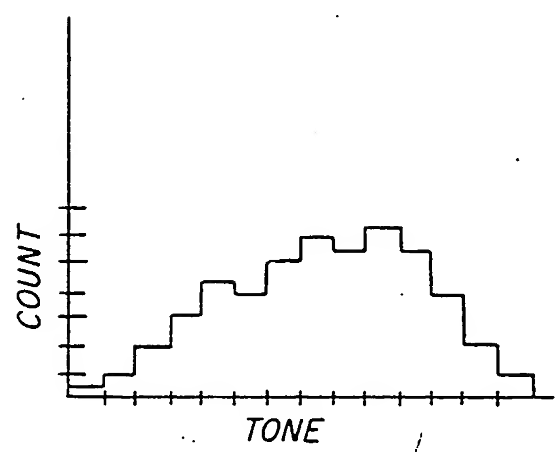
COUNT
TONE

FIG. 4

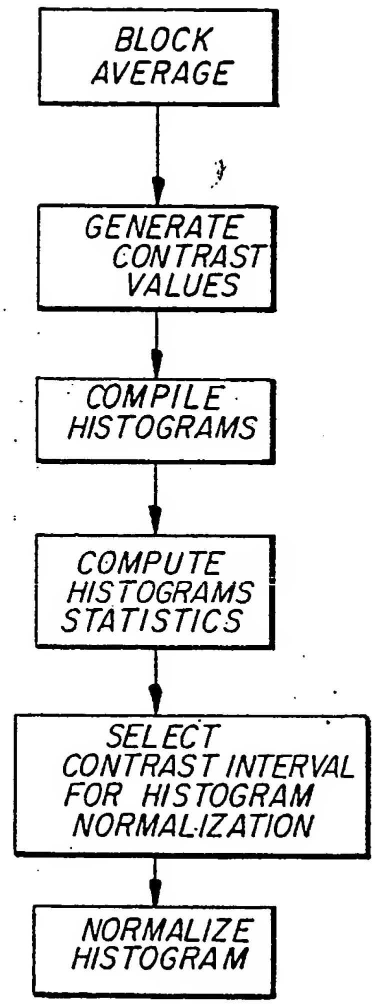
BLOCK AVERAGE
GENERATE CONTRAST VALUES
COMPILE HISTOGRAMS
COMPUTE HISTOGRAMS STATISTICS
SELECT CONTRAST INTERVAL FOR HISTOGRAM NORMALIZATION
NORMALIZE HISTOGRAM

FIG.5

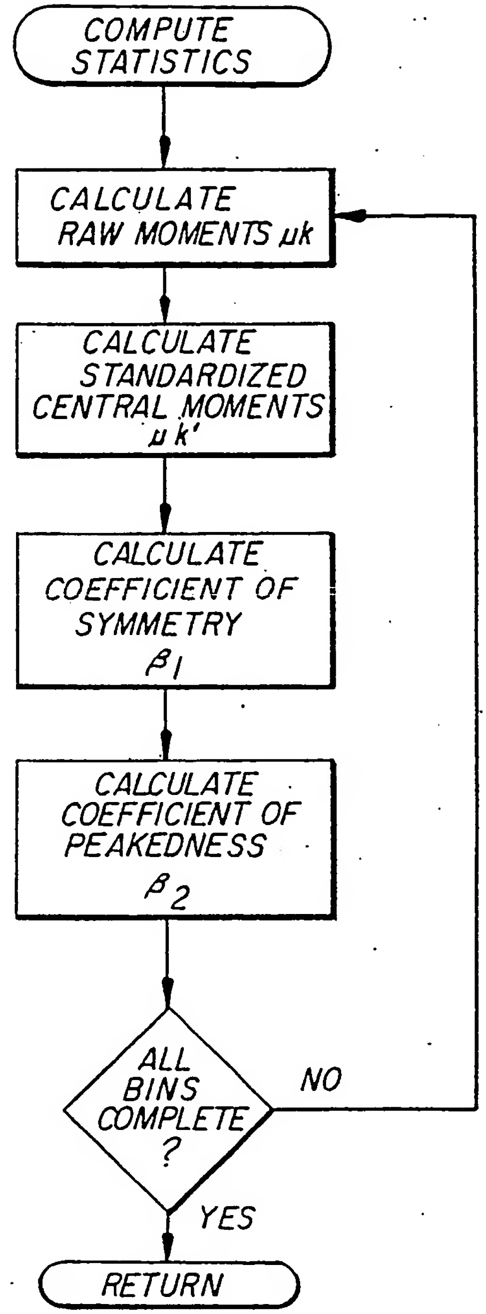
COMPUTE STATISTICS
CALCULATE RAW MOMENTS μk
CALCULATE STANDARDIZED CENTRAL MOMENTS μk'
CALCULATE COEFFICIENT OF SYMMETRY β1
CALCULATE COEFFICIENT OF PEAKEDNESS β2
ALL BINS COMPLETE ?
NO
YES
RETURN

FIG. 6

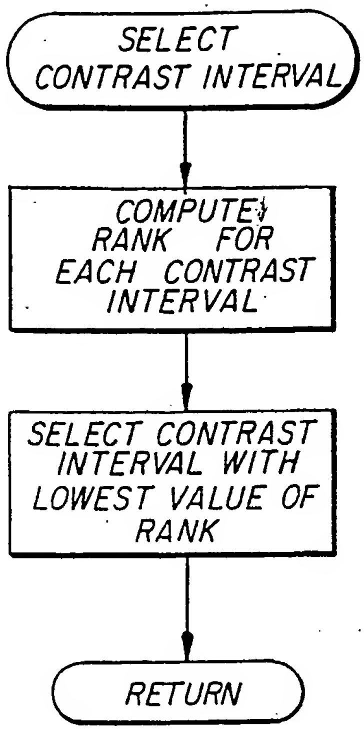
SELECT CONTRAST INTERVAL
COMPUTE RANK FOR EACH CONTRAST INTERVAL
SELECT CONTRAST INTERVAL WITH LOWEST VALUE OF RANK
RETURN

FIG. 7A

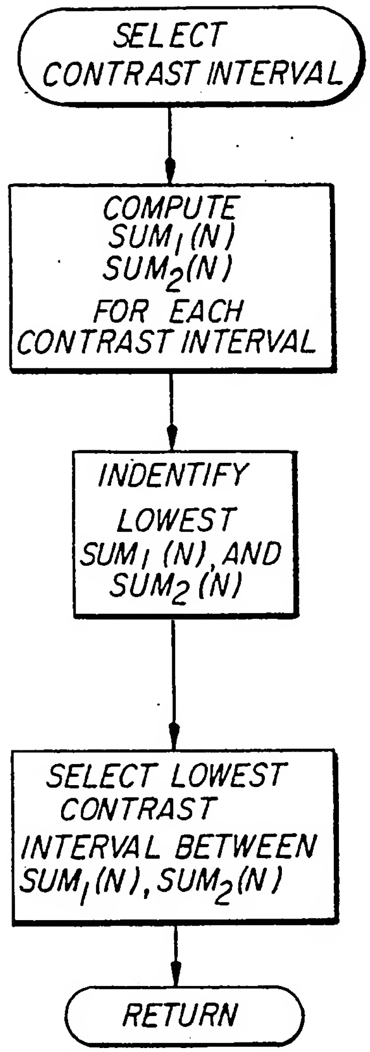
SELECT CONTRAST INTERVAL
COMPUTE SUM1(N) SUM2(N) FOR EACH CONTRAST INTERVAL
INDENTIFY LOWEST SUM1 (N), AND SUM2 (N)
SELECT LOWEST CONTRAST INTERVAL BETWEEN SUM1(N), SUM2(N)
RETURN

FIG. 7B

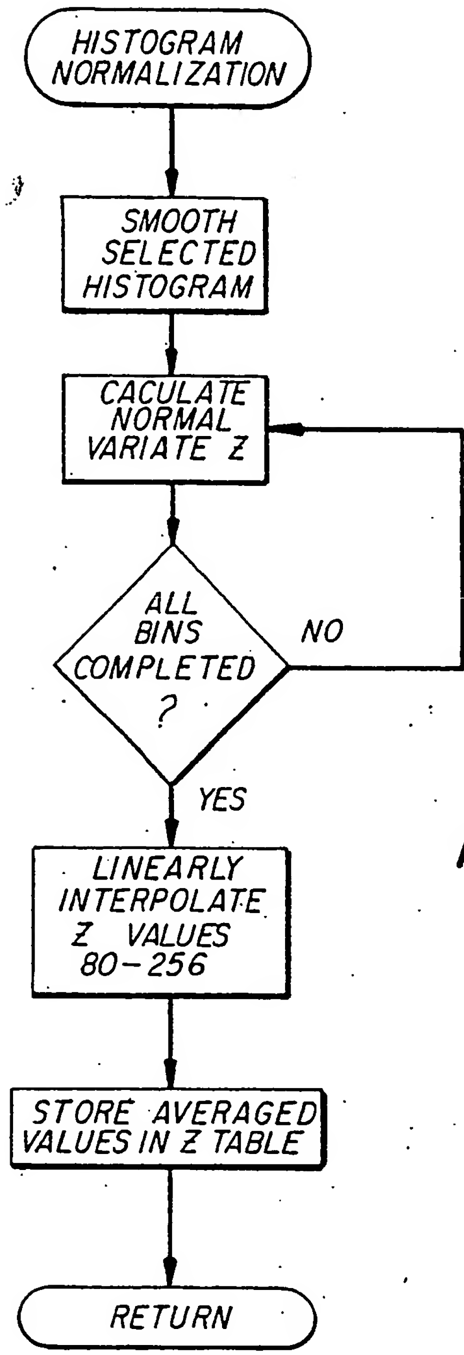
HISTOGRAM NORMALIZATION
SMOOTH SELECTED HISTOGRAM
CACULATE NORMAL VARIATE Z
ALL BINS COMPLETED ?
NO
YES
LINEARLY INTERPOLATE Z VALUES 80-256
STORE AVERAGED VALUES IN Z TABLE
RETURN

FIG.8

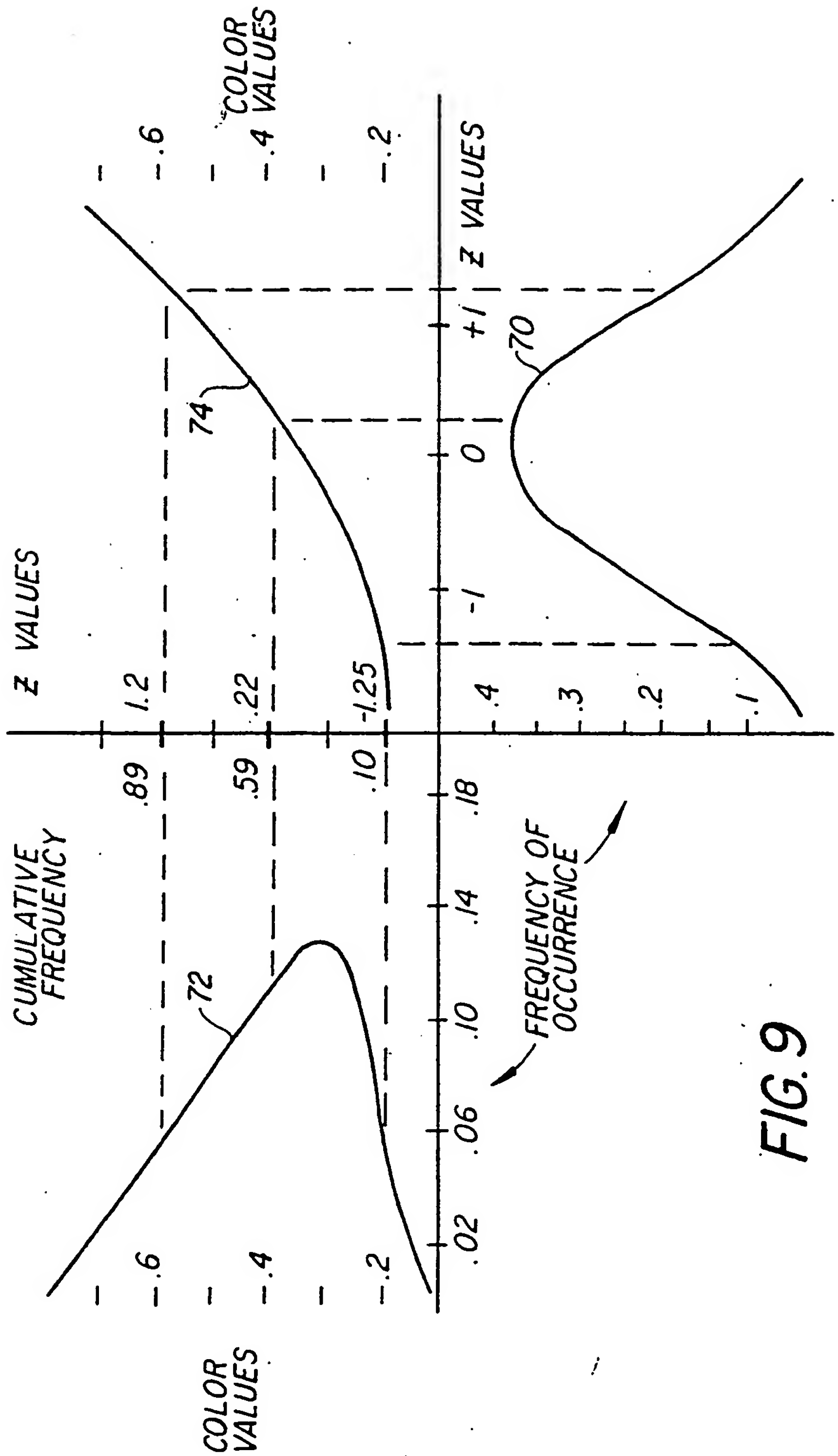
COLOR VALUES
.6
.4
.2
Z VALUES
+1
0
-1
70
74
Z VALUES
1.2
.22
-1.25
.4
.3
.2
.1
CUMULATIVE FREQUENCY
.89
.59
.10
.18
.14
.10
.06
.02
72
FREQUENCY OF OCCURRENCE
.6
.4
.2
COLOR VALUES

FIG. 9

INTERNATIONAL SEARCH REPORT

International Application No PCT/US 86/00823

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [8]

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC^4: H 04 N 1/46

II. FIELDS SEARCHED

Minimum Documentation Searched [7]

Classification System	Classification Symbols
IPC^4	H 04 N 1/46 G 06 F 15/68

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [9]

Category *	Citation of Document, [11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No. [13]
A	Proceedings of the Twelfth International Conference of Printing Research Institutes, Versailles, France, IPC Science and Technology Press, 1974, Guildford, (GB) Yu Ovchinnikov et al.:"A new approach to programming in photomechanical reproduction", pages 160-163, see page 163, lines 1-24	1,13
	--	
A	Communications of the ACM, volume 21, no. 10, October 1978, Philadelphia, (US) S.K. Chang et al.:"Optimal histogram matching by monotone gray level transformation", pages 835-840, see page 835, right-hand column, lines 3-47	1
	--	
A	Proceedings of the IEEE Computer Society Conference on Pattern Recognition and Image Processing, 31 May - 2 June 1978, New York, (US) J.S. Lee:"Digital image processing by use of local statistics", pages 55-61, see page 56, left-hand column, line 20 -	./.

* Special categories of cited documents: [10]

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
24th July 1986	22 AUG 1986
International Searching Authority	**Signature of Authorized Officer**
EUROPEAN PATENT OFFICE	M. VAN MOL

Form PCT/ISA/210 (second sheet) (January 1985)

III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)

Category *	Citation of Document, with indication, where appropriate, of the relevant passages	Relevant to Claim No
	right-hand column, line 23	2
	--	
A	Optical Engineering, volume 21, no. 5, September - October 1982, Bellingham, (US) D.E. Troxel et al.:"Interactive enhancement of Tone scale ", pages 841-846, see page 842, left-hand column, line 11 - page 843, left-hand column, line 22	3
